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ABSTRACT

Recent years have seen an increasing number of studies on safety climate across multiple industries. These studies include efforts in validating the role of safety climate as an indicator for safety behavior and organizational safety management. Although extensive studies empirically validated the relationships among the safety culture constructs and safety outcomes, the theoretical underlying relationships are not well defined. Moreover, the results of these studies are not consistent based on various theoretical hypothesis and methodological approaches. There lacks a systematic analysis of these theories and methodologies that were utilized in these studies to identify the inconsistency. Lastly, the relationships were established across multiple industries with a broad view of measuring safety climate and safety performance. The validation of safety climate in the construction industry remains challenging. This research studies the conceptual basis and methodologies within safety climate literature, with a focus on the construction industry, and discusses the gaps in establishing the relationships. Two types of gaps are identified: conceptual and methodological gaps. Conceptual gaps include the misalignment in concepts and the misalignment in domain context. Methodological gaps refer to the misalignment between the theoretical implications of safety climate and its measurement in terms of data collection and/or data analysis approaches. The main outcome is the need to define a framework to validate leading indicators, such as safety climate, based upon the underlying relationships specific in the construction industry.

INTRODUCTION

Construction safety and health, as defined by Bubshait and Almohawis (1994), refers to the degree to which the general conditions promote the completion of a project without major accidents or injuries. As indicated by the definition, safety performance has long been assessed by lagging indicators in construction, such as the Occupational Safety and Health Administration (OSHA) Recordable Injury Rate (RIR), days away, restricted work, or transfer (DART) injury rate; and experience modification ratings (EMRs). These indicators have provided information on the construction industry averages and served as foundations to cross compare construction firms (Hinze et al. 2013). However, Glendon and Litherland (2001), Chen and Jin (2012), and many others have discussed the problems of lagging indicators, such as their insufficient sensitiveness, inaccurate reporting, and ignorance of risk exposure. Moreover, due to the complex and dynamic nature of the construction workplace and the fragmentation of multiple stakeholders, it is challenging to identify and measure the 'true' safety performance of an active project based on these lagging indicators (Fang et al. 2006; Lingard et al. 2010[a]). Consequently, there has been a shift of research interest towards the application of leading indicators to predict safety performance. While lagging indicators focus on the outcome of accidents, leading

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indicators evaluate the level of effectiveness of the safety process (Hinze et al. 2013). Leading indicators monitor management programs or individual behaviors linked to accident prevention, which help to identify problematic areas that will potentially lead to accidents and improve the safety performance through managing positive safety behaviors (Hale 2009). Leading safety indicators derive their importance from their ability to causally and proactively link with safety outcomes (Guo and Yiu 2015). Unlike the lagging indicators, leading indicators reduce the need to wait for the system to fail in order to identify weaknesses and to take remedial action (Flin et al. 2000).

Safety climate is one of the most widely used leading indicators (Hallowell et al. 2013; Guo and Yiu 2015). In the construction industry, extensive studies have been focused on safety climate measurement (Mohamed 2002; Choudhry et al. 2009), and establishing the link between safety climate and safety performance (Glendon and Litherland 2001; Mohamed 2002; Lingard et al. 2010[a]). Recent meta-analytic studies have indicated a positive relationship between safety climate and safety performance (Clarke 2006; Christian et al. 2009). However, these results were based on aggregated data from multiple industries and contexts, which may neglect the safety issues in one specific context. Moreover, the safety performance indicators vary across different studies and the approaches to capture these indicators are not standardized. Therefore, the mechanism of safety climate in mediating or impacting safety performance is not fully addressed, especially in a specific context, i.e. the construction industry. This research reviews recent directions in the increasing body of literature on safety climate, and explores the implications of safety climate and the conceptual and methodological gaps between safety climate and its current research and implementation within the construction industry. The discussion helps to understand the concept of safety climate, which leads to establishing a theoretical model of safety climate. Clearer understanding of safety climate has implications for project stakeholders to proactively manage safety risks on construction projects.

Although the term "safety climate" has been widely used among high-risk industries, there is little consensus on the concept of safety climate, and the related term safety culture. A number of studies have addressed the conceptual ambiguity on what safety climate actually means (Choudhry et al. 2007; Haukelid 2008). The concept of safety culture and safety climate was originally derived from organizational culture, which is separated from other characteristics of an organization, such as business strategy and decision-making (Zohar 1980; Choudhry et al. 2007). There is debate within the safety literature regarding the use of the term safety climate and safety culture, and if any difference exists between the concepts (O'Conner et al. 2011). The terms are used interchangeably in many areas of the safety literature (Cox and Flin 1998; Mohamed 2003). Cooper (2000) distinguished the concepts and specified three aspects of safety culture including psychological, behavioral, and situational. Among these aspects, the psychological aspect refers to how individuals perceive safety and safety management systems, and is referred to as safety climate. O'Conner et al. (2011) stated that culture represented the more stable and enduring characteristics of the organization while climate represent a more visible manifestation of the culture. Fang et al. (2006) suggested that safety climate is a "snapshot" of safety culture. The ambiguity of the concepts poses theoretical challenges in not only measuring, but fully defining and understanding safety climate and its implications to project and organizational safety. Zohar (1980) first introduced the concept of safety climate and defined it as, "a summary of molar perceptions that employees share about their work environment." Although the interpretation of safety climate varies with context, there are some common themes that can be drawn from these definitions. First, all of the definitions mentioned "perceptions;" therefore, it differentiates itself from other aspects of culture, such as behaviors. It is based upon the psychological aspects of culture. Second, safety climate is an organizational indicator which is shared by the employees within their working environments. This implies there may be multiple levels of safety climate within one organization as there may be multiple working environments. Safety climate, or points-of-view, is suggested to be measurable. This indicates that there should be descriptive metrics to quantify safety climate at certain points of time, which further suggests that safety climate is dynamic and is subject to change.

THE RELATIONSHIP BETWEEN SAFETY CLIMATE AND SAFETY BEHAVIOR

It is widely agreed that safety climate reflects the psychology aspect of the organization culture related to safety. In social learning theory, Bandura (1977) described a triad consisting of the person, environment (situation) and behavior in the model of reciprocal determinism, as shown in Figure 1. The model of reciprocal determinism explains the psychosocial functioning of the triadic reciprocal causation, where each individual's internal psychological factors, the environment they are in and the behavior they engage in, all operate as interacting feedback loops that influence each other bi-directionally. Geller (1997) applied Bandura’s theory and developed the Total Safety Culture Model, to illustrate the descriptive composition of safety culture of the three constructs without specifying the relationships among the domains. Cooper (2000) further developed a reciprocal safety culture model of three constructs, based on Bandura’s model, including safety climate as the personal construct, safety management system as the environment construct, and safety behavior, as well as the logic of reciprocal determinism. The major differences between Geller and Cooper’s interpretations of the triad constructs reside in the use of the term “environment” and “situation”. Geller (1997) used environment based on an engineering approach and Cooper (2000) emphasized on the organizational strategies and policies. Due to the close relationship between safety culture and safety climate, the safety culture model is presented to understand the underlying causal relationships among the concepts of safety climate within the context of organizations. The safety culture models outline the manner in which safety culture is thought to be embedded in an organization’s practices and safety management systems (Choudhry et al. 2007).

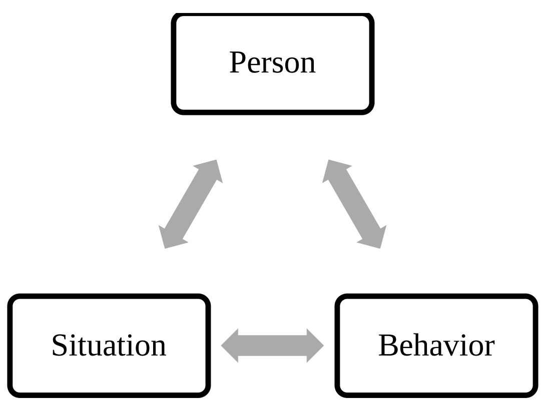

Figure 1. Bandura’s (1977) model of reciprocal determinism

Safety climate and safety behavior

In the safety culture models mentioned, safety climate reflects the internal psychological construct and interacts with the environment and behavior constructs. The assumption underlying the link between safety climate and safety behavior is that employees' awareness of safety priorities among competing goals and a standard for action would drive behavior; therefore, a more positive safety climate encourages safe behavior (Clarke 2006; Johnson 2007). Empirical studies have been focused on assessing the validity of safety climate in impacting safety outcomes by correlating the scale or factor scores of safety climate against safety behavior and accident rates. The validity of safety climate, as suggested by Cooper and Phillips (2004), includes the concurrent validity (i.e. safety performance at the time of distribution) and predictive validity (i.e., forecast future safety performance). Mohamed (2002) surveyed 68 construction workers from 10 different companies in Australia using a comprehensive questionnaire to measure perceived safety climate and safe work behavior, and found significant positive relationship between them. Choudhry et al. (2009) identified a similar result based on a survey of 1294 construction workers in Hong Kong. Although different questionnaires were used, both studies statistically demonstrated the concurrent validity of safety climate in impacting self-reported safety behavior. Pousette et al. (2008) used a different approach to examine the predictive validity of safety climate, where multiple samples from a construction project in Sweden from successive time points were used. Safety climate was found to significantly predict self-reported safety behavior 7 months later with previous safety behavior under control. However, Glendon and Litherland (2001) found a contradictory result. Instead of self-reported safety behavior, a behavioral observation measure was developed for 92 construction and maintenance workers. Multiple regression results showed no significant relationship between safety climate and observational safety behavior.

One of the reasons to explain the inconsistency of results can be explained by the psychological nature of safety climate. While psychosocial safety climate is conceptualized as the organizational policies, practices, and procedures for the protection of worker psychological health and safety (Dollard and Neser 2013), safety behavior focuses on specific actions or behaviors exhibited by workers (Burke et al. 2002). This also explains the alignment of safety climate and self-reported safety behavior, as both reflect the psychological aspect of safety. Furthermore, behavior may not be as sensitive as psychological perceptions in capturing the changes related to safety at workplace, since unsafe behavior is often rare and infrequent. Last but not lease, there are some mediating factors between safety climate and behavior, such as safety motivation (Neal and Griffin 2006), safety participation (Clarke 2006), personality (Fang et al. 2006). These mediating factors create conceptual gaps among safety climate, safety attitudes, individual and group safety behavior. The mechanism is even more complex in construction, where the behavior of the workforce is not as standardized as in production industry, and the activities are performed within the work crew instead of individual activities (Rowlinson 2004). Therefore, it is important to use a triangulated approach to measure safety to provide a full picture of safety within an organization (Glendon and Litherland 2001).

Safety climate and safety outcomes

Some other studies are focused on validating the relationship between safety climate and safety outcome. Although safety outcomes were not included in the safety culture models mentioned, some behavior-based safety studies have argued that behavior-based approaches are effective in improving safety performance (Lingard and Rowlinson 1998). Zohar (2002) suggested a theoretical path from safety climate to accidents via behavior. Extensive studies in safety climate attempt to assess the predictive validity of safety climate in forecasting accidents. Sparer et al. (2013) found no significant relationship between safety climate and the EMR, lost time, and OSHA recordable injury rate. Chen et al. (2013) found that incident rates and safety violation rates are related with safety climate in short term (4 months) but not related in long term (17 months). Patel and Jha (2015) suggested that instead of a linear relationship, there should be a three-layer feed-forward-back-propagation neural network among the safety climate factors and the self-reported safety behavior. Lingard et al. (2010) [a] developed a typology of safety climate including safety climate strength and levels. Safety climate strength means the degree of consensus concerning climate perceptions within members of a group. The level of safety climate refers to the relative priority placed upon safety within a workgroup as perceived by members of that group. The results indicated that lost time and medical treatment injury rates are related with safety climate strength, but unrelated with safety climate levels.

The explanations for the discrepancy between safety climate and safety outcomes are similar to the discussion in previous section. Safety climate, as a psychological indicator, differs from safety outcome indicators, which are based on facts, such as the frequency and/or the severity of accidents, injuries, etc. While safety climate measures the attitudes and perceptions of individuals or workgroups before accidents, safety outcome indicators reflect the result of incidents. Moreover, safety climate measures the group perceptions of their workplace by aggregating individual perceptions, while other safety outcome indicators indicate the results of individual behavior. The relationship between individual safety perceptions and individual behavior is mediated by safety compliance and safety participation (Neal et al. 2000). However, as most safety climate studies measure the group safety perceptions without analysis at individual level, there is potential misalignment between the group perception and the outcome at individual level.

THE RELATIONSHIP BETWEEN SAFETY CLIMATE AND ENVIRONMENT

Safety climate relates to employees' perceptions of safety, or the extent to which the work environment is perceived as personally beneficial or detrimental (Fugas et al. 2012). This concept links the situational and psychological processes related to safety. Organizational safety management and strategies are often viewed as the core indicators of the environment/situation. However, a number of other situational aspects, such as job risks, are important aspects of the context surrounding safety in organizations, even if they are not indicators of safety climate themselves (Beus et al. 2010). This can creates gaps when considering the predictive validity of safety climate. Moreover, the multiple levels of organization structure create gaps between safety management development and implementation, impacting the perceptions of the workforce.

Safety climate and physical environment

Previous research has focused on organizational and/or group management in defining the environment construct of safety culture (Cooper 2000; Choudhry 2007). As Geller (1996) suggested, physical conditions are part of the working environment. Job risk, as it is commonly assessed in safety climate measures, refers to the level of risk inherent in the job being performed (Beus et al. 2010). The job risk being measured in safety climate surveys includes self-reported risk taking, perceptions of risk/hazards on the worksite, and attitudes towards risk and safety (Flin et al. 2000). Safety climate has focused on organizational interventions, but few studies within safety climate literature have assessed workplace safety from a technical engineering perspective. On the other hand, extensive studies have been performed in the areas of job safety/hazard analysis (Carter and Smith 2006; Perlman et al. 2014) and accident causation (Abdelhamid and Everett 2000; Mitropoulos et al. 2005; Ale et al. 2008), for modeling risk assessment and accident. However, the role of workplace conditions in shaping the employees' perception towards safety is not fully addressed.

Workplace conditions refer to the physical scenarios of the workforce at different points of time, such as the physical layout of the workplace or work location, the status of tools, equipment, and/or material (Guo and Yiu 2015). As safety climate reflects the perceptual aspects of safety, human-related managerial or operational factors are more emphasized, while the physical workplace conditions are often neglected. In the construction context, compared with production industry, the workplace condition varies greatly at different points of time and the trade composition is often different (Carter and Smith 2006; Perlman et al. 2014). This means when measuring the safety climate at different points of time, the respondents are often not the same group and they are experiencing different levels of risk exposures. The dynamic workplace conditions when measuring the construction project safety climate is not addressed by previous studies.

Safety climate and organizational safety management

Along with the gap between organizational and physical environment, there exists potential misalignment within the organizational environment itself. Previous studies have emphasized the role of management commitment as a central element of safety climate (Zohar 1980; Petal and Jha 2015). The perceptions of the workforce are rooted in the mission, value or policies developed and advocated by the top management. Formal organizational safety program is explicit and stable, relating to overt statements and formal procedures applicable across situations, which is shared by the organization and often communicated in written documents, training courses, or scheduled meetings. The actual safety plan, on the other hand, is dynamic and situation dependent, which must be derived from one's own or others' experiences and observations of senior, middle, and lower management patterns of action concerning safety issues across a variety of situations (Zohar 2002). The potential misalignment is enlarged in the construction industry due to its nature of subcontracting.. Construction subcontractors are often engaged in complex relationships both horizontally (i.e. with other trades that are engaged under the same general contractor) and vertically (i.e. with the general contractor or other subcontractors in the case of multi-layered subcontracting) (Lingard et al. 2010[b]). This implies the potential misalignment between the safety commitment of their organization and other organizations. To make things more complicated, the changing conditions of other project goals (financial situation, production, etc.) are likely to affect the extent of the gap. When conflicted with other project goals, the project management is likely to make decisions that are not aligned with the organizational safety commitment. For example, when the project is behind schedule, the managerial priority may not be given to safety since the goal may conflict with the production goals (Han et al. 2014).

While the implementation of the safety program is usually a top-down process on most construction projects, the safety climate survey reflects the bottom-up perceptions in terms of safety policies, practices, and procedures (Lingard et al. 2010[b]). However, the differing emphasis between the approaches makes it difficult to assess the organizational safety management commitment from the workforce's perceptions. Hunter et al. (2007) suggests that there are a number of leadership activities that are not likely witnessed by a subordinate, including meetings with other leaders, meetings with clients, and more cognitively-based actions such as planning or strategy development. This provides theoretical explanation for identifying the gap between organizational safety management commitment and the perceptions of the workforce. Therefore, the potential misalignment between the organizational safety commitment and the project specific safety plans, as well as the cognitive gap between the management commitment and the workforce perception, should be considered when analyzing the impact of organizational management commitment on safety climate.

THE MEASUREMENT OF SAFETY CLIMATE

Extensive research has been focused on safety climate measurement, either through a factorial structure (Mohamed 2002; Pousette et al. 2008) or a multi-level structure (Lingard et al. 2010[a]; Sparer et al. 2013). While existing research has contributed significantly to our understanding of the implications of safety climate, there are some methodological characteristics of the research which should be taken into consideration in the interpretation of the findings.

Methodologies to measure safety climate

Although there are experimental and qualitative studies which have provided valuable insight in conceptualizing safety climate assessment (Haukelid 2008; Atak and Kingma 2011), the vast majority of studies have relied on survey data and statistical data analysis techniques (Hopkins 2006). Questionnaire is considered to be a quick instrument because a large amount of data can be collected with fairly minimal effort required by either the researchers, or the participants (Guldenmund 2007). Questionnaires are also appealing as they allow for quantitative comparisons between different variables, thus provide statistical basis to benchmark safety climate across different sectors and to validate the relationship between safety climate and other safety indicators (O'Connor et al. 2011). Despite the prevalence, a number of researchers raised questions in terms of the validity and reliability of the methodology measuring safety climate. Guldenmund (2007) argued that certain conditions apply which might make the self-administered questionnaire less useful in organizational culture research. The conditions include insufficient participants, interval scales (Likert scales) rather than ordinal, ambiguity in attitudes and perceptions, external organization conditions. Antonsen (2009) compared the safety climate survey results with the results of a qualitative investigation after a major incident of a Norwegian oil and gas platform. The safety climate survey results were predominantly positive which failed to identify the organizational problems that were later identified by the incident investigations. One of the methodological explanations was that the questionnaire-based approach provided a narrower analytical scope than the causal investigation, which only focused on perceptions rather than the way in which other cultural interacts (such as risks) with other aspects of the organization. O'Connor et al. (2011) investigated the descriptive analysis of a large sample of safety climate survey data (n=110,014) collected over 10 years from U.S. Naval aircrew using the Command Safety Assessment Survey, and demonstrated that there was substantial non-random response bias associated with the data. The bias was due to the negative effect on participant motivation of a number of factors, such as questionnaire design, lack of a belief in the importance of the response, participant fatigue, and questionnaire administration. Thus a triangulation of quantitative and qualitative data was recommended for assessing safety climate of an organization. The advantages and disadvantages of the questionnaire survey approach themselves impact the analyzing and understanding about the dimensions, antecedents, and consequences of safety climate. This creates challenges to understand the "true" safety climate compared with the "measured" safety climate. For example, a majority of studies have provided empirical evidence of the positive correlation between safety climate and self-reported safety behavior. Although research on behavior-based safety provides theoretical explanations for the relationship between safety climate and self-reported safety behavior (Fugas et al. 2012), there is still a high risk of reporting biases during the process of acquiring the data.

Another methodological characteristic of current safety climate assessment is the aggregation of individual perceptions. It is generally agreed to view organizational climate as *shared* employee perceptions regarding psychologically meaningful attributes of the organizational environment (Zohar 2010). Pousette et al. (2008) argued that members of a work group agree to a greater extent about their perceptions of their social environment than about how they value safety as individuals. Organizational climate originates with individual members' experiences and perceptions which gradually become socially shared through a variety of mechanisms (Kozlowski and Klein 2000). By aggregating the individual perceptions, the impacts of variances, such as personal knowledge, previous experiences, and individual job/task hazards, are minimized. However, these factors impact the safety behavior of individuals from an accident causation perspective. From the data analysis perspective, the averages of the scores are focused to understand the mean perceptions of the work group. The underlying mechanism of how individual perceptions become shared should be addressed to understand the "true" safety climate.

Table 1. A summary of Research Methods in measuring safety culture constructs

	Research Methods	Safety Culture Constructs	Studies
Quantitative Research	Questionnaire-based Survey	Safety Climate	Mohamed 2002; Fang et al. 2006; Lingard et al. 2010;
		Self-reported Safety Behavior	Mohamed 2002; Pousette et al. 2008; Choudhry et al. 2009; Patel and Jha 2015
	Structured Interviews/	Safety Management Program	N/A
		Safety Outcome	Sparer et al. 2013
	Structured Observation	Safety Behavior	Glendon and Litherland 2001
Qualitative Research	Interview	Safety Climate Safety Management Program	Antonsen 2009
	Focus Group	Safety Management Program	N/A
	Observation	Safety Behavior	N/A

Table 1 summarizes the research methods that are used to measure safety culture constructs. Quantitative data represents the dominant approach for measuring safety climate constructs, especially for questionnaire-based surveys. Quantitative approaches help control or eliminate individual variances, thus allowing a standardized examination of the data, but it also creates bias to reflect the actual context (Zou et al. 2014). For safety climate measurement, it creates diagnosis challenges to understand the underlying problematic areas of safety management. On the other hand, qualitative data is interpretive and emphasizes the specific cases that arise in the actual context (Neuman 2011). A lack of enough samples is commonly considered to be the major limitation of qualitative data (Grix 2004). Therefore a mixed methodology is suggested for conducting safety climate research (Antonsen 2009; O'Connor et al. 2011). By adopting a mixed research methodology, it is expected that the findings will become more relevant and useful to construction industry and practitioners, while at the same time contributing to the advancement of conceptual understanding and theory development (Zou et al. 2014).

Safety climate measurement tools

As the common themes of the safety climate definition concerns the workforces' safety-related perception within their working environment, the measurement of such perception depends on the tools used. There are two scale-development strategies for the tools: universal and industry-specific (Zohar 2002). Universal scale, or generic scale, tools incorporate context-free questions based on the respondents' cumulative experience in their working environment. One example of universal question would be "I feel that the management is concerned about my safety." The other strategy incorporates items or issues embedded in specific contexts. For example, Sing et al. (2007) developed the safety climate measurement tool for the health care industry. The respondents were asked about their agreement on industry-specific statements of "Things 'fall between the cracks' when transferring patients from one unit to another;" and "My unit emphasizes patient safety procedures and goals to new hires in their first 6 months of work." Ciavarelli (2003) developed another tool to measure the safety climate in the aviation industry. Contextual statements include "All of our aircraft mechanics are well trained and meet stringent certification standards;" and "Maintenance management encourages aircraft mechanics to work by the book." Although safety climate has been widely applied in construction, there are few studies that incorporate the specific issues related to safety in the construction industry (Zohar 2002). While the universal or generic scales allow longitudinal comparison across industries, the industry-specific scales incorporate contextual norms and benchmarks, which offer the advantage of collecting rich diagnostic information that uncovers the nature of the employees' emphasis on assessing the safety of their working environment (Zohar 2002).

The construction industry has its unique characteristics of being temporary, dynamic and fragmented nature. In terms of the temporary characteristic, there should be metrics developed to measure the collaboration of multiple stakeholders. Since the contractors play a dominant role in creating the construction project safety climate, with the owner and designer being removed from the day-to-day safety management, previous studies have focused on the role of contractors when measuring the project safety climate, with little emphasis on owner's involvement and the architect/engineer's impact. Secondly, the construction working environment is dynamic with different levels of risks and different trades. Construction sites, unlike other production facilities, undergo changes in topography, topology and work conditions throughout the duration of the projects (Rozenfeld et al. 2010). When measuring the safety climate of the construction project, the staging or timing effect should be incorporated. The last characteristic is the fragmentation, with the subcontractor workforce isolated from the organization of general contractor or construction manager, even from their own organization; it is difficult to differentiate the management commitment of their firm with the overall project management from the workers' perceptions. However, there are challenges to conduct longitudinal studies to measure construction project safety climate. It is time-consuming and expensive to collect safety climate data regularly over the project lifecycle. Moreover, since safety climate data are perceptions, it may be very sensitive to environmental constructs, thus making it difficult to determine the causes of safety climate variations.

DISCUSSION

Despite the popularity of safety climate in construction industry, there exist several theoretical and methodological gaps in understanding the nature of safety climate and the relationships between safety climate and other safety aspects. This research identifies these gaps based on the safety culture model.

Theoretical Constructs	Safety Culture Constructs	Relationship with Construction Safety Climate
Behavior	Safety Behavior	tested but various results
	Safety Outcomes	tested but various results
Environment	Safety Management	not tested
	Physical Workplace Conditions	not tested

Table 2. Summary of Relationships among Safety Culture Constructs

Table 2 summarizes the gaps that are discussed in this paper. Based on the Bandura's social learning theory, there are three constructs related to the individual psychosocial functioning, including environment, behavior, and person. Geller (1997) and Cooper (2000) applied the theory and identified the three constructs in the realm of safety. While the person construct is interpreted as perceived safety climate, the behavior construct is identified as safety behavior and safety performance. Extensive studies have focused on validating the relationship between safety climate and safety behavior/outcomes. However, the results of the validation are various due to the different indicators selected and the research techniques applied. The environmental construct is interpreted as safety management and physical workplace conditions. While the role of safety management in creating safety climate is fully discussed, the relationship between them has not been validated by quantitative data analysis, especially in construction. The role of physical workplace conditions has been neglected in construction safety climate research. The knowledge gap exists in conceptualizing the relationship as well as methodologically measuring and validating the relationship.

Table 3. A summary of gaps in safety climate research

Type of Gaps	Definition	Example
Conceptual Gaps	Misalignment in concepts	Safety climate and safety behavior
		Safety climate and safety outcome
	Misalignment in domain context	Safety climate and physical environment
		safety climate and safety management
Methodological Gaps	Misalignment in theoretical implications and empirical measurement	Safety climate measurement

Table 3 summarizes the knowledge gaps that are discussed in this paper. There are two types of gaps within these relationships: conceptual gaps and methodological gaps. Conceptual gaps include the misalignment of knowledge due to different concept or domain context. The first conceptual gaps refer to the misalignment in concepts or definitions of construction within the same level due to different emphasis on the nature of the constructs or the underlying factors within the constructs. For example, the misalignment between safety climate and safety behavior is primarily due to the different emphasis on the psychological and behavioral aspects of safety. Similarly, the different concepts of leading indicator and lagging indicator contribute to be one of the explanations for the gap between safety climate and safety outcome. The misalignment in concepts or definitions is difficult to overcome because they are determined by the nature of the constructs. However, exploring the mechanism of these gaps helps to understand the causal links among the concepts and the mediating factors in the links. For instance, efforts have been made to determine role of safety leadership as a mediating factor in linking safety climate and safety management commitment (Clarke 2011). The other type of conceptual gap refers to the misalignment of scope in definition when contextualize the construct in a specific realm. An example would be the gap between safety climate and physical environment. When interpreting the environment construct in the context of safety, organizational environment is emphasized. The impact of physical environment on safety climate is not fully addressed. This kind of conceptual gap could be addressed by analyzing the underlying concepts within each construct and the characteristics of the specific context, thus making context another important factor in conceptualizing safety culture. The methodological gaps, on the other hand, refer to the misalignment between the theoretical implications of the constructs and the measurement of the constructs due to sample selection, data collection and/or data analysis approaches. To control the methodological gaps, especially for the questionnaire-based approach, efforts should be made through methodology design and survey administration.

The implications of the mechanisms within the conceptual and methodological gaps provide foundations for developing a framework of construction project safety climate. Based on the three major safety culture constructs, the contextual characteristics of the construction industry should be taken into account, when defining the scope of the constructs. The construction environment is considered to be dynamic across project phases. The dynamics include different risk exposures caused by changing physical structures and activities, the different composition of trades as respondents of survey, and the evolving cognitive process of shared perception among stakeholders. As safety climate provides a "snapshot" of the current status of organizational safety culture, the time or phasing muist be taken into account. Previous studies have focused on the static safety climate of one project or one organization without analyzing the time or phasing of the project. Furthermore, the divergence of safety culture among multiple stakeholders within the workgroup and the impacts of physical workplace risks are often neglected in conceptualizing construction project safety climate. The complexity of the construction project environment and the divergent sensitivities of the cultural constructs over time offer limited opportunities for empirical verification. Due to the limitation of the questionnaire-based approach, a triangulation of qualitative and quantitative approaches should be incorporated in safety climate methodology design.

Based on the discussion, future research should focus on conceptualizing safety climate within the construction project contexts, and developing methodologies for robustly validating the relationships among the conceptual constructs and contextual characteristics.

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